Magnetism in moiré heterostructures

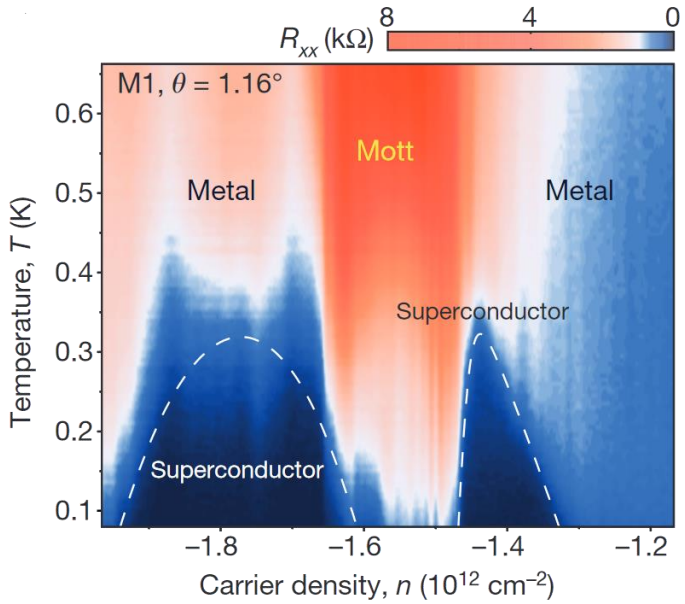
Aaron Sharpe

EPiQS Postdoctoral Symposium

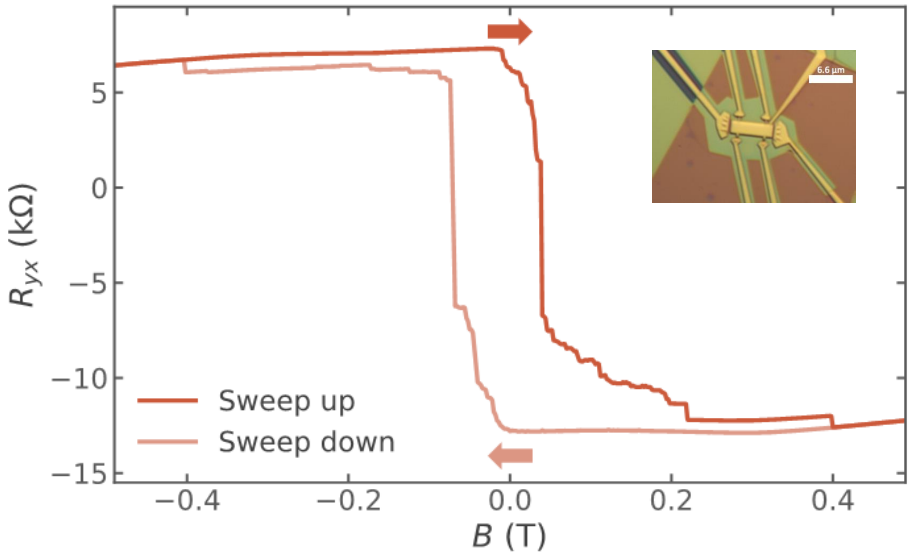
June 4th 2024

Overview: TBG's varying phase diagram

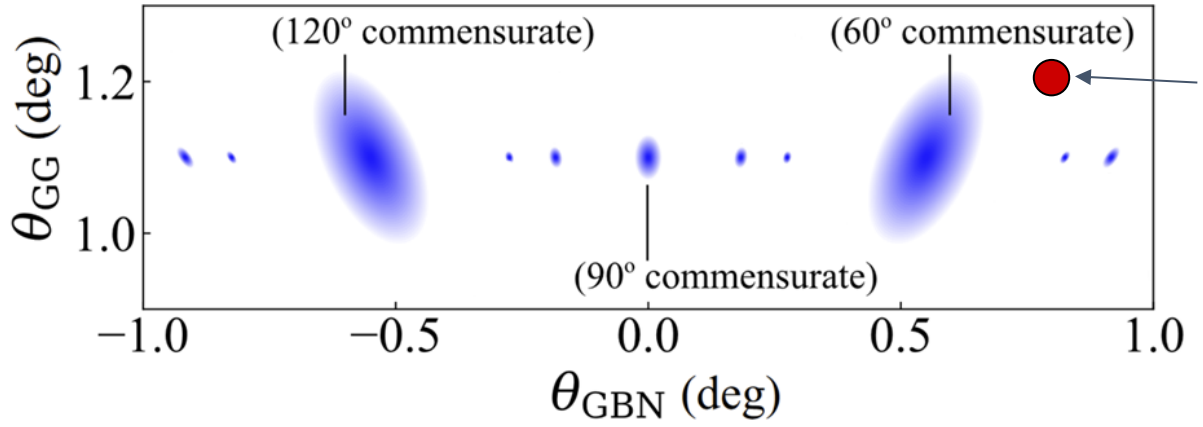
Superconductivity



Orbital ferromagnetism



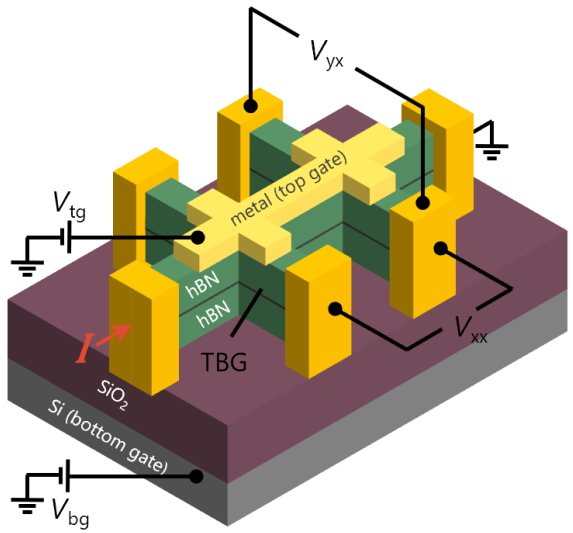
hBN's role is complicated

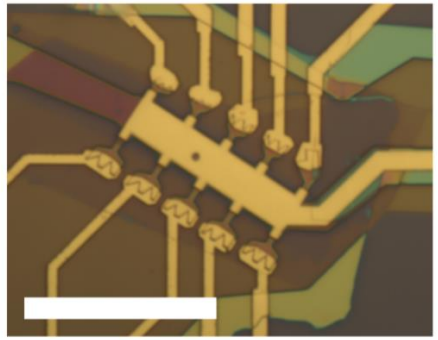


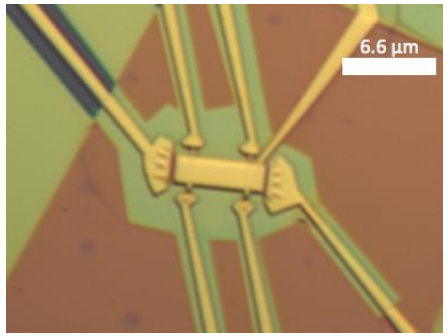
Sharpe, Fox, et al.

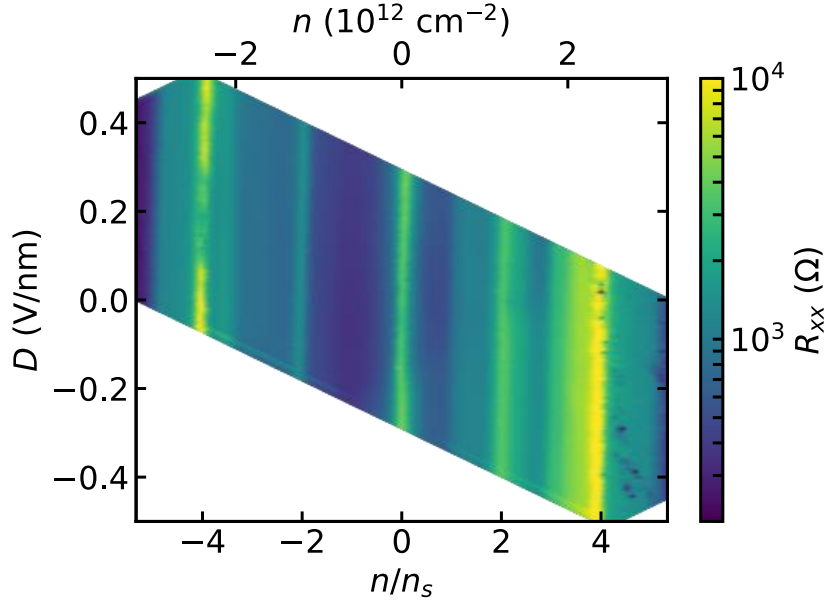
Cao, et al. Nature (2018)
Sharpe, Fox, et al. Science (2019)
Shi et al. PRB (2021)

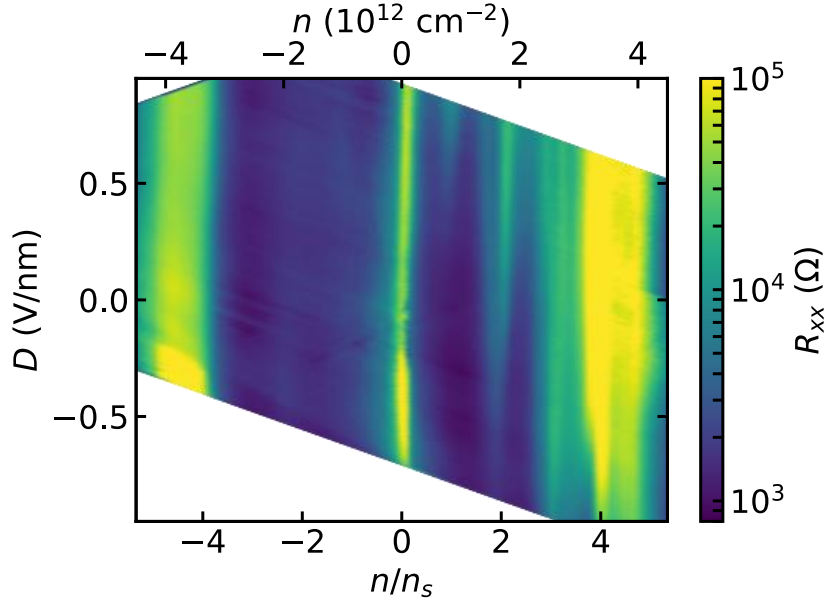
Atypical twisted bilayer graphene (TBG)





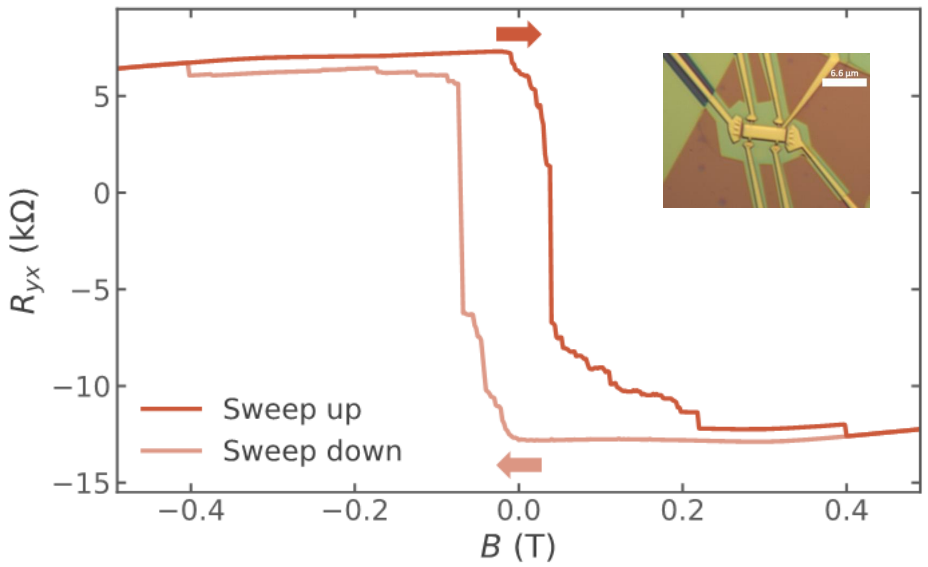


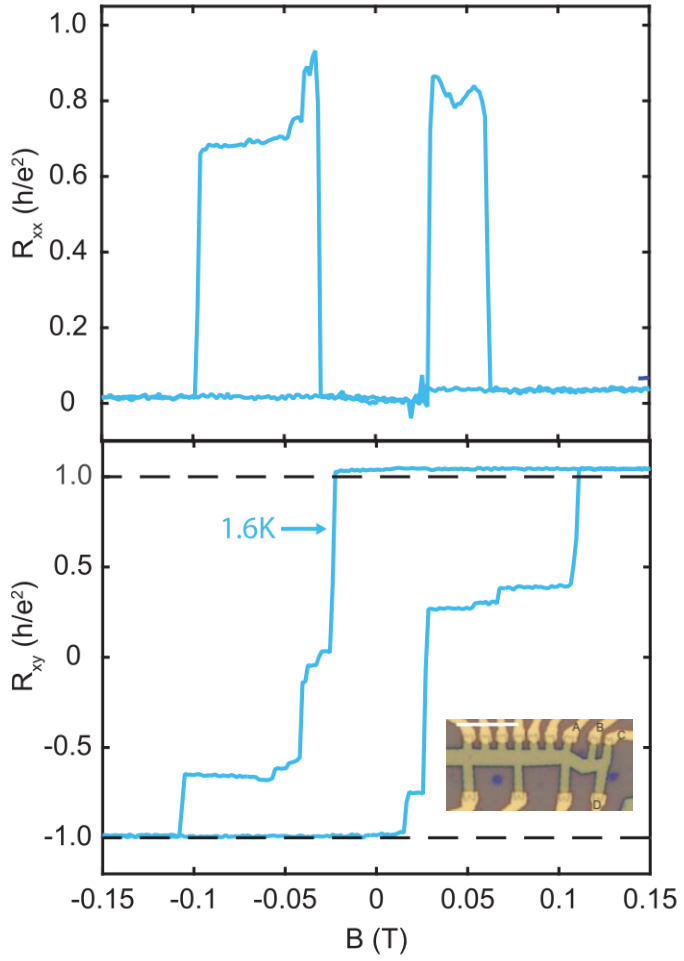




Sharpe, Fox, et al. Science (2019)

(Quantum) anomalous Hall at $n/n_s = 3$

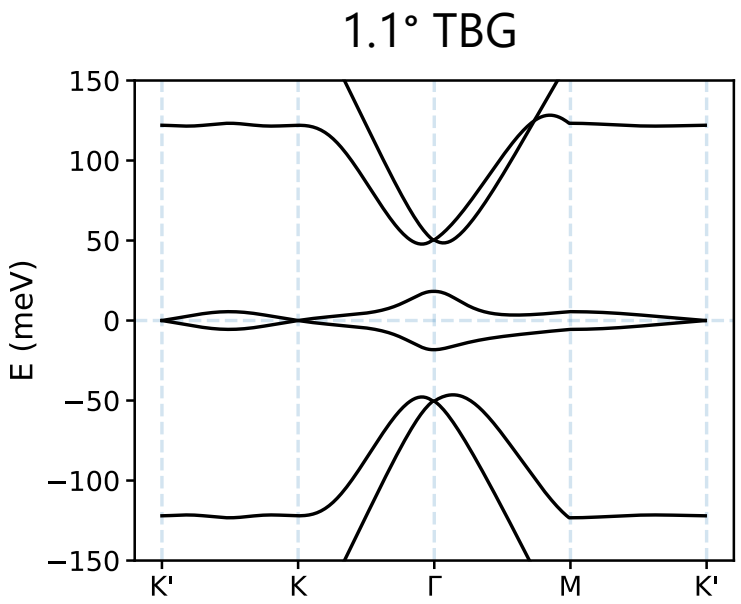




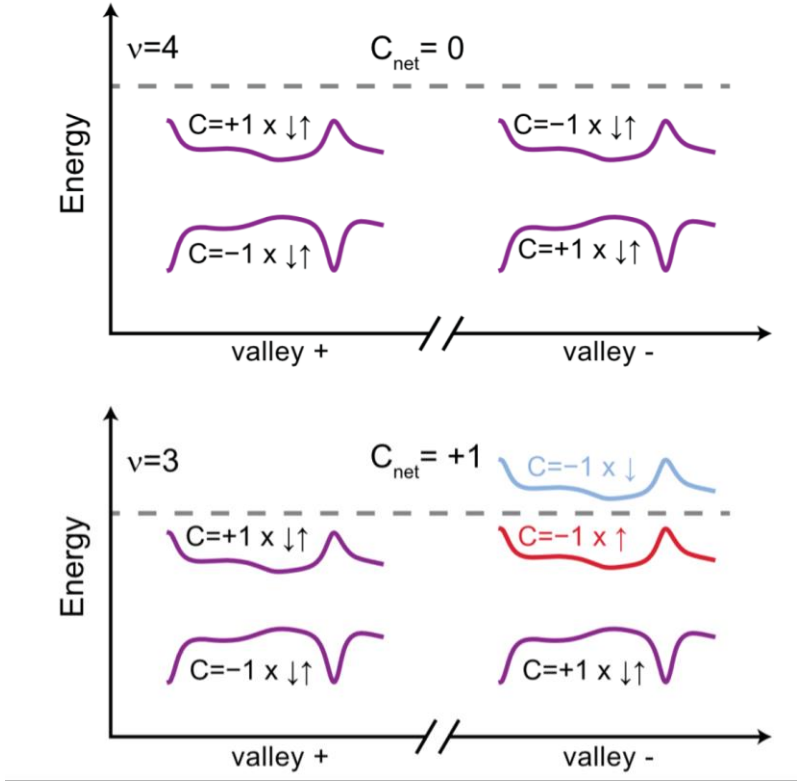
Sharpe, Fox, et al. Science (2019)
Serlin, et al. Science (2020)

Orbital nature:
Sharpe, et al. Nano Lett. (2021)
Tschirhart, et al. Science (2021)

hBN alignment is the key for MATBG?



hBN
alignment
+
TRS breaking



https://git.sr.ht/~spxtr/bm_model
Sharpe, Fox, et al. Science (2019)
Serlin, et al. Science (2020)
Zhang, et al. PRB (2019)
Bultinck, et al. PRL (2020)
Xie and MacDonald, PRL (2020)

(Q)AH is quite common in moirés!

MATBG aligned/commensurate with hBN:
A. Sharpe, E. Fox et al. Science (2019)
M. Serlin, et al. Science (2020)
Tschirhart, et al. Science (2021)
A. Sharpe, E. Fox et al. Nano Lett. (2021)
P. Stepanov, et al. PRL (2021)
C-C. Tseng, et al. Nat. Phys (2022)
S. Grover, et al. Nat. Phys (2022)

MATBG + WSe2:
J-X. Lin, et al. Science (2022)

Rhombohedral graphene
Trilayer aligned to hBN (FCI?)
G. Chen, A. Sharpe, et al. Nature (2020)
G. Chen, A. Sharpe, et al. Nano Lett. (2022)
Quadlayer + WSe2
Y. Sha et al. Science (2024)
Pentalayer (FCI when aligned to hBN)
T. Han, et al. Nature (2023)
Z. Lu, et al. Nature (2024)
Hexalayer aligned to hBN (FCI?)
J. Xie, et al. arXiv:2405.16944

Twisted bilayer MoTe2 (FCI)
E. Anderson, et al. Science (2023)
J. Cai, et al. Nature (2023)
Y. Zeng, et al. Nature (2023)
H. Park, et al. Nature (2023)
F.. Xu, et al. PRX (2023)

AB-stacked MoTe2/WSe2:
T. Li, et al. Nature (2021)

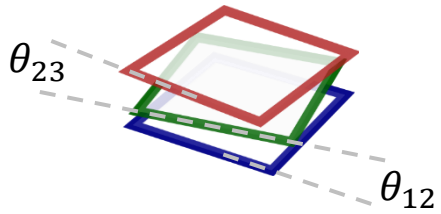
Twisted mono-bilayer graphene:
S. Chen, et al. Nat. Phys (2020)
H. Polshyn, et al. Nature (2020)
M. He, et al. Nat. Comms (2021)

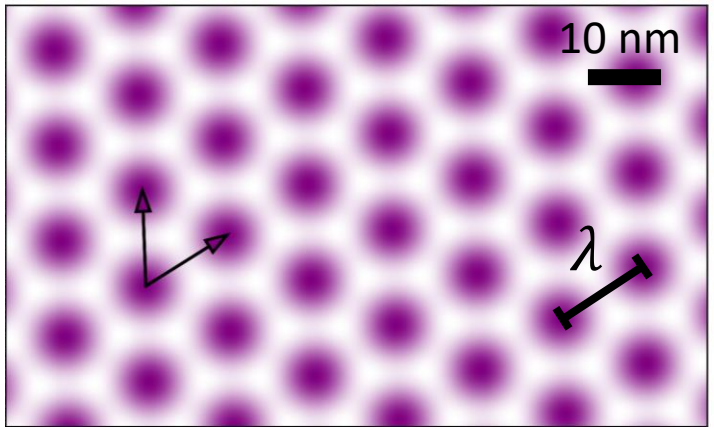
Twisted double bilayer graphene:
[AB-AB] M. Kuiri, et al. Nat. Comms (2022)
[AB-BA] M. He, et al. Nano Lett. (2023)

Helical trilayer graphene
L-Q Xia, et al. arXiv:2310.12204

M+N graphene:
D. Waters, et al. arXiv:2405.05913

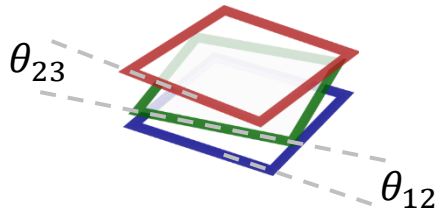
From moiré to multimoiré

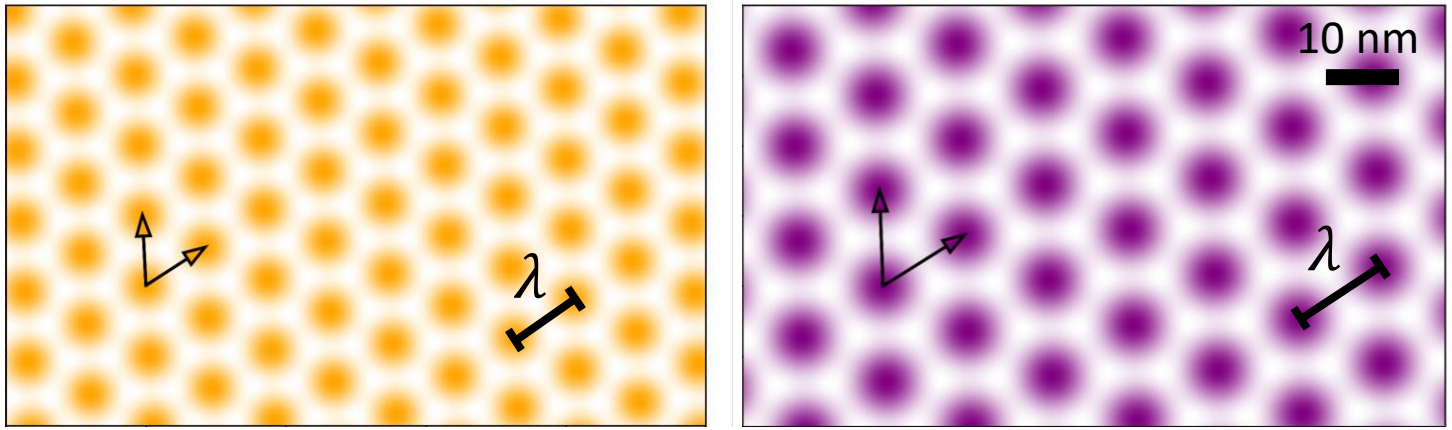




Yang, et al. arXiv:2310.12961
Nakatsuji, et al. PRX (2023)
Foo, et al. PRR (2024)
Bistritzer and MacDonald, PNAS (2011)

From moiré to multimoiré





Yang, et al. arXiv:2310.12961
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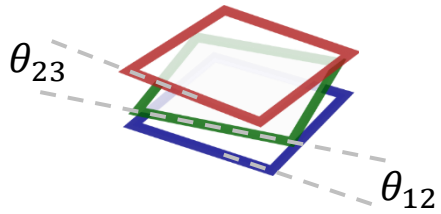
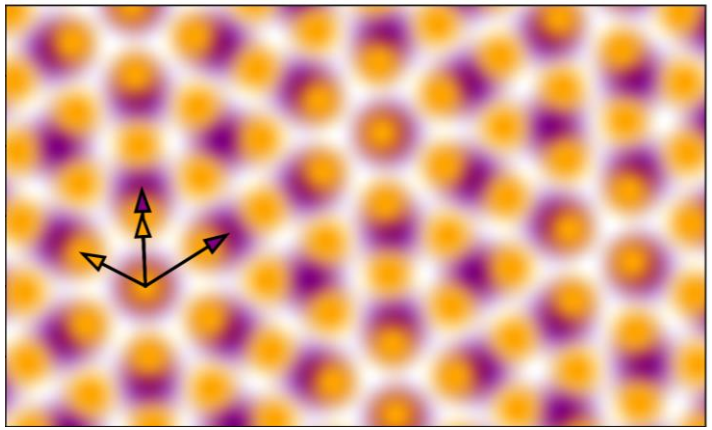
Bistritzer and MacDonald, PNAS (2011)

From moiré to multimoiré

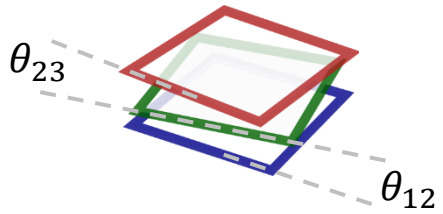




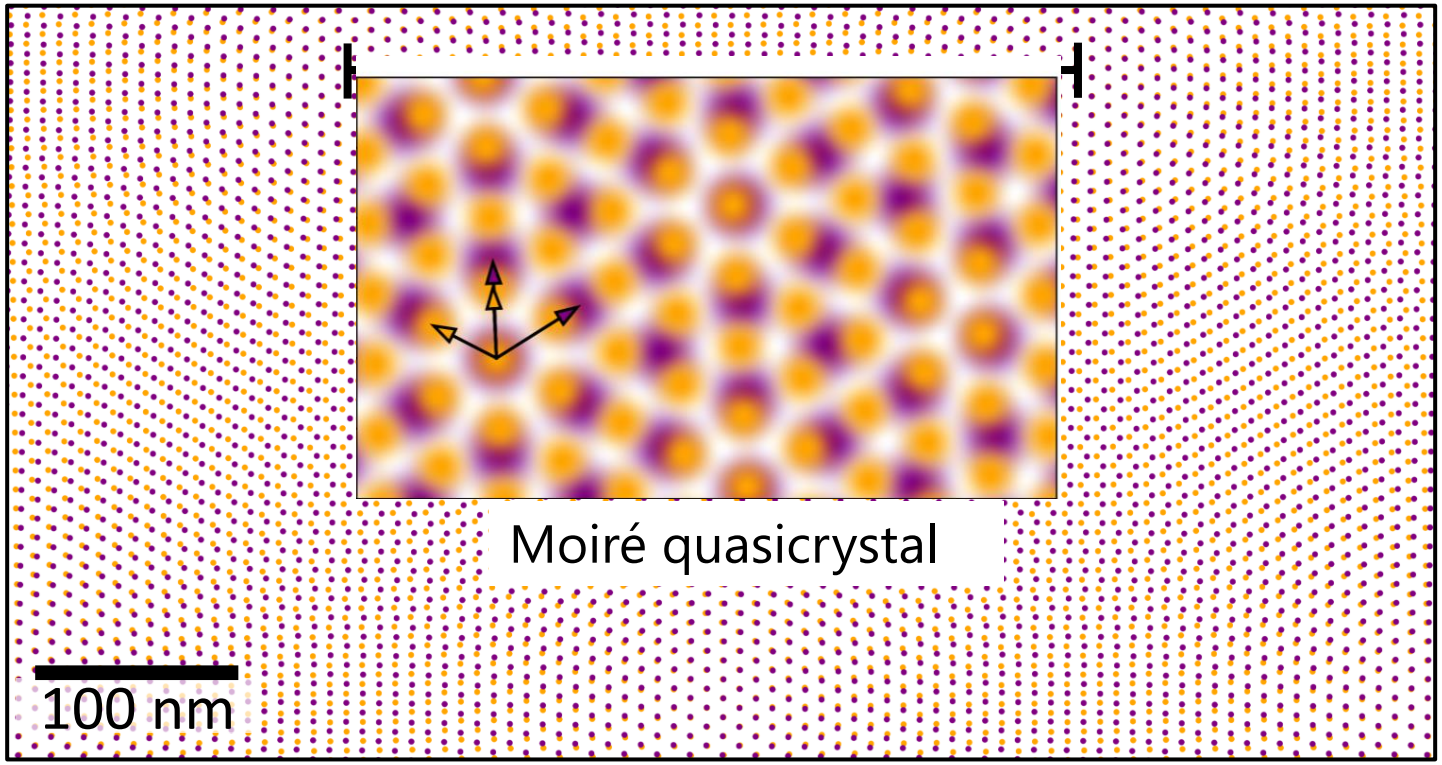
Moiré quasicrystal

Yang, et al. arXiv:2310.12961
Nakatsuji, et al. PRX (2023)
Foo, et al. PRR (2024)
Bistritzer and MacDonald, PNAS (2011)

From moiré to multimoiré

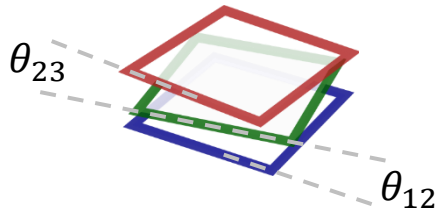


Supermoiré: $\lambda_{\mathrm{sm}} = \dfrac{\lambda_{\mathrm{m}}}{\theta} = \dfrac{a}{\theta^2}$

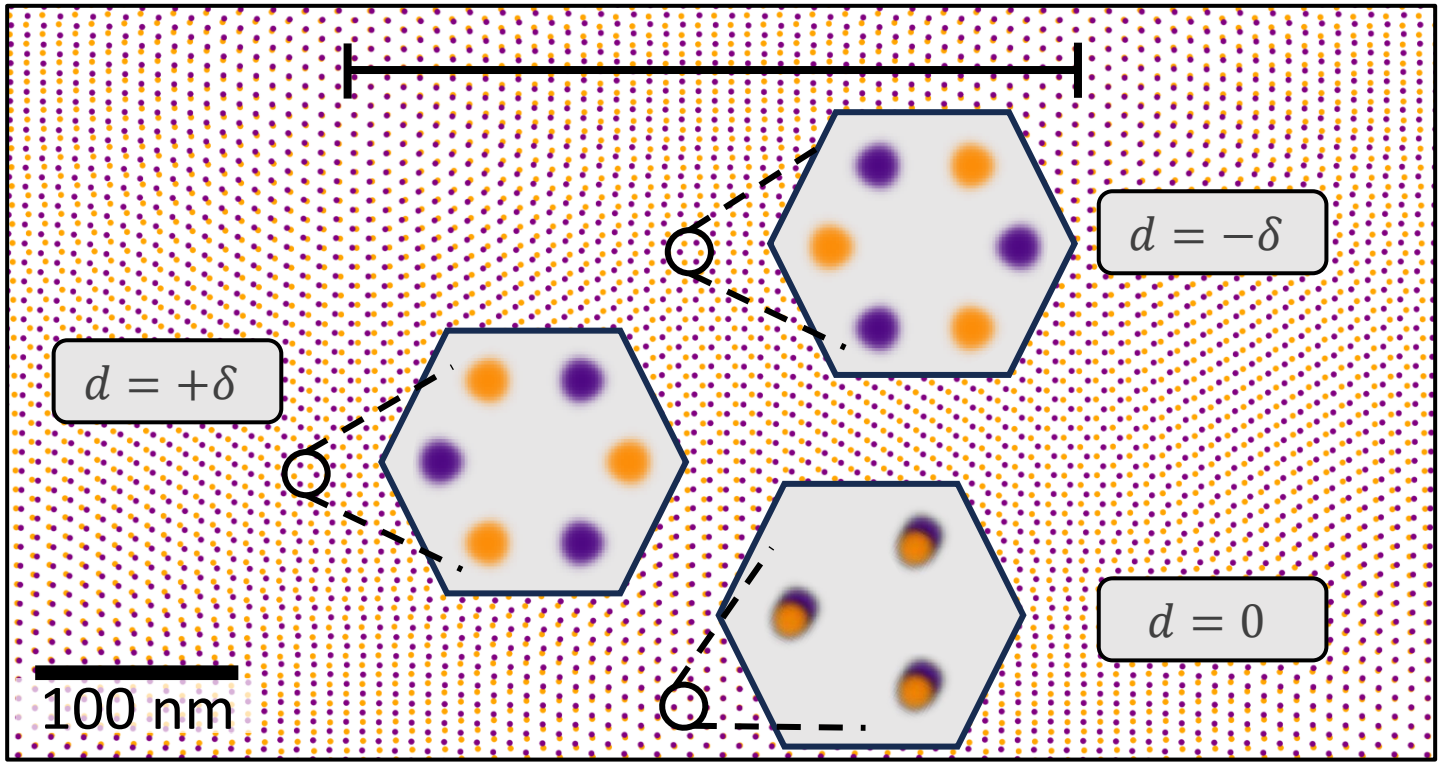


Yang, et al. arXiv:2310.12961
Nakatsuji, et al. PRX (2023)
Foo, et al. PRR (2024)
Bistritzer and MacDonald, PNAS (2011)

From moiré to multimoiré

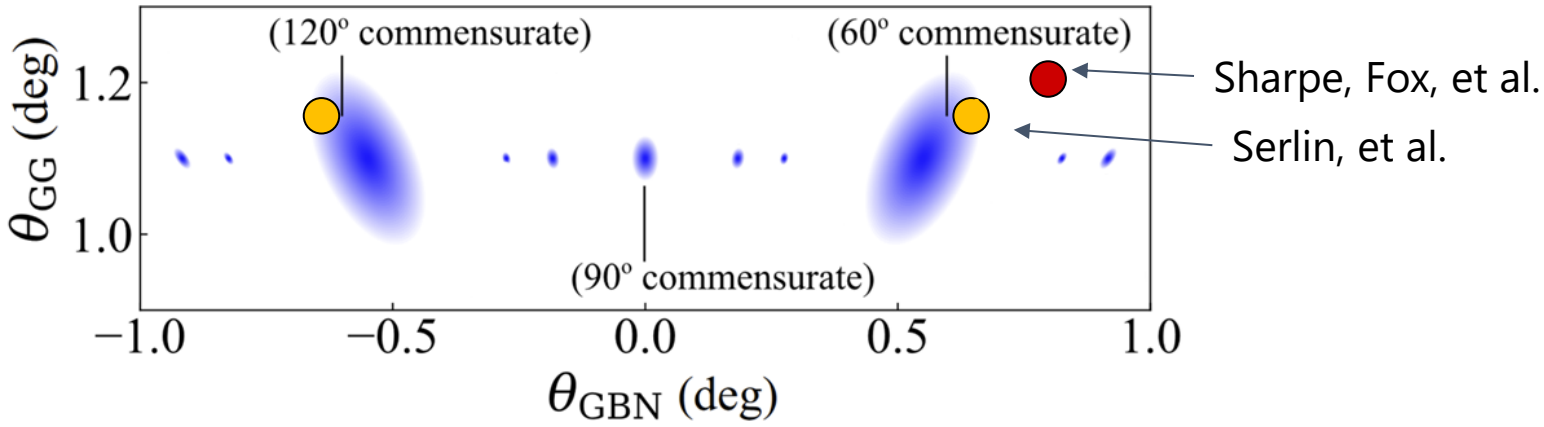


Supermoiré: $\lambda_{sm} = \frac{\lambda_m}{\theta} = \frac{a}{\theta^2}$



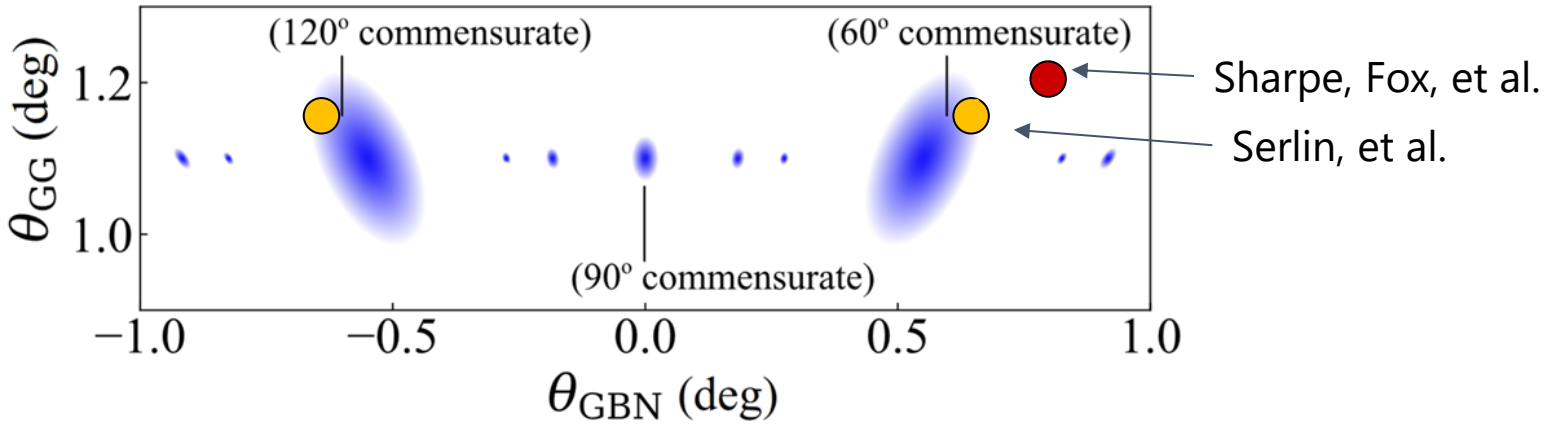
Yang, et al. arXiv:2310.12961
Nakatsuji, et al. PRX (2023)
Foo, et al. PRR (2024)
Bistritzer and MacDonald, PNAS (2011)

TBG/hBN multimoiré



Shi et al. PRB (2021)

TBG/hBN multimoiré



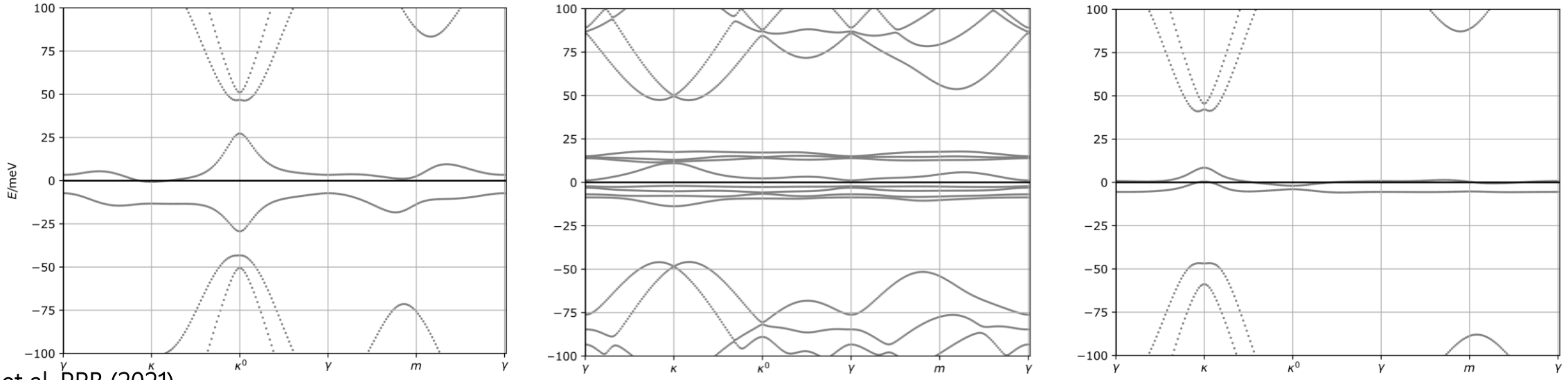
Sharpe, Fox, et al.

Serlin, et al.

120 commensurate

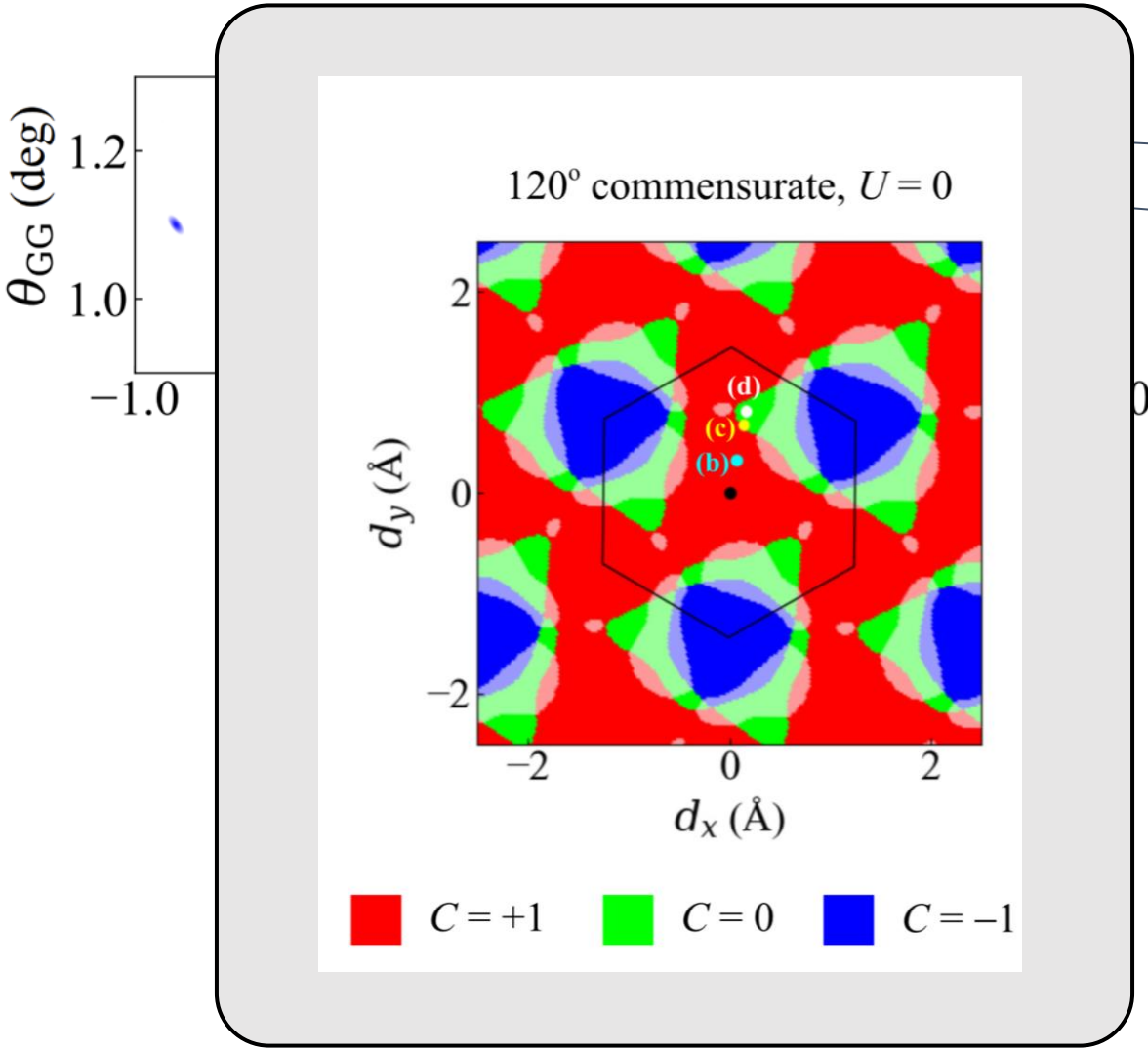
90 commensurate

60 commensurate



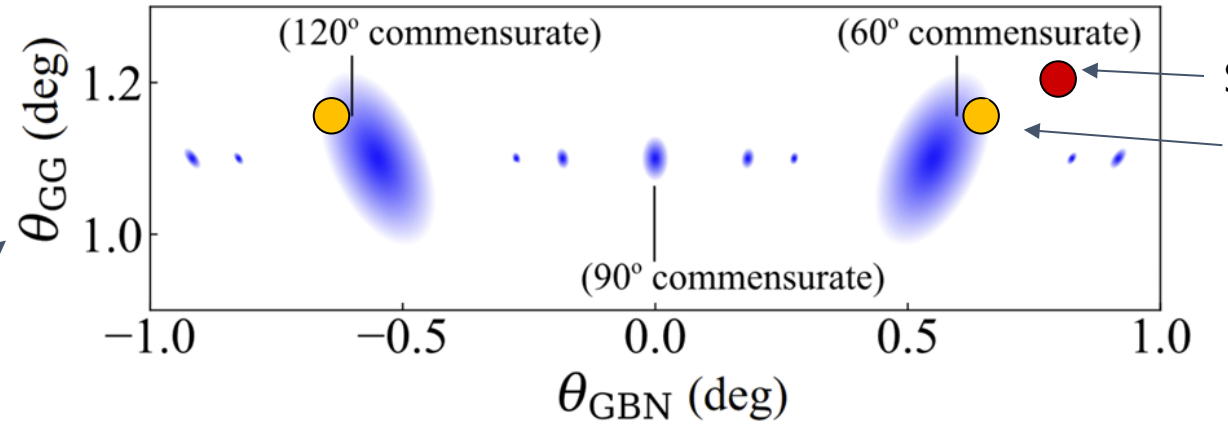
Shi et al. PRB (2021)

TBG/hBN multimoiré



Shi et al. PRB (2021)

TBG/hBN multimoiré



Sharpe, Fox, et al.

Serlin, et al.

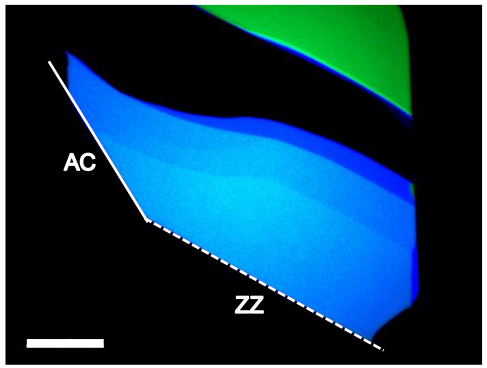
'Cut and Stack'

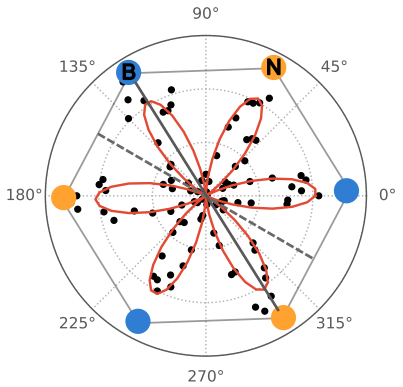
Align crystal facets*

Shi et al. PRB (2021)

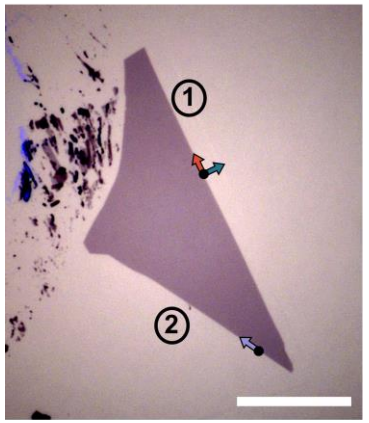
Deterministic fab with rapid feedback

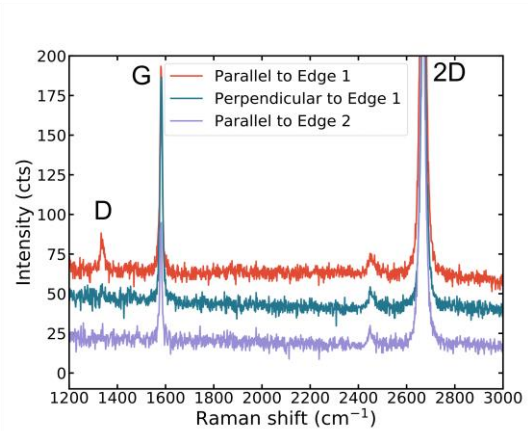
Second harmonic generation for hBN



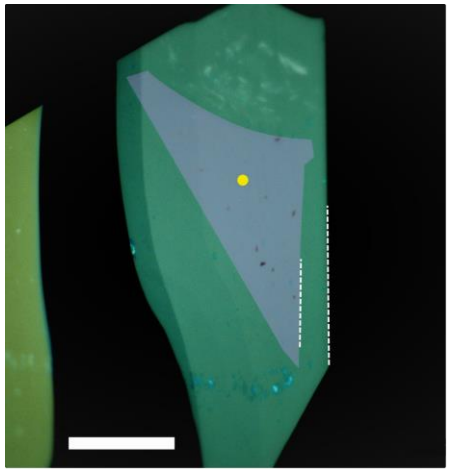


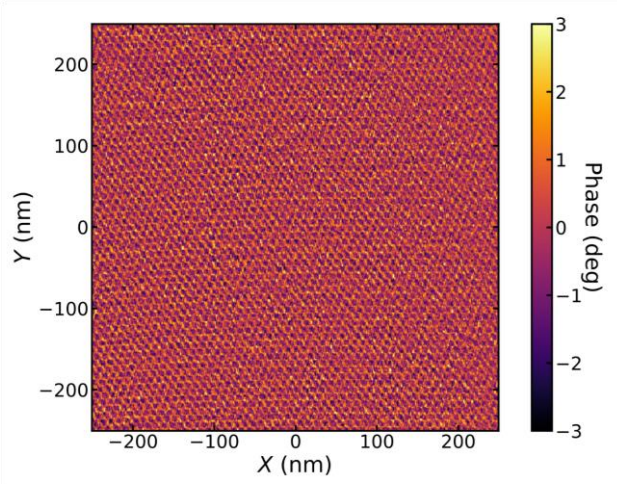
Polarized Raman for graphene





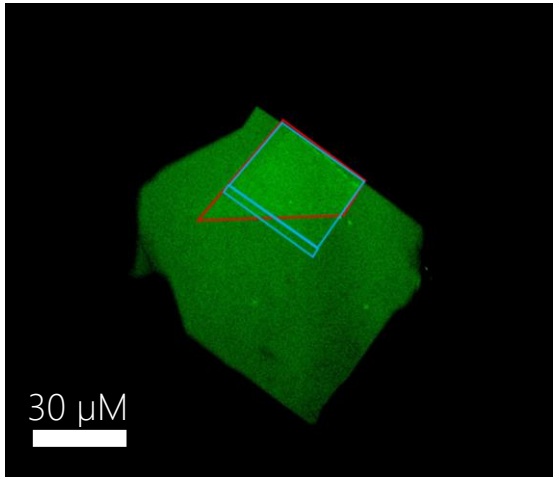
Torsional force microscopy for moirés

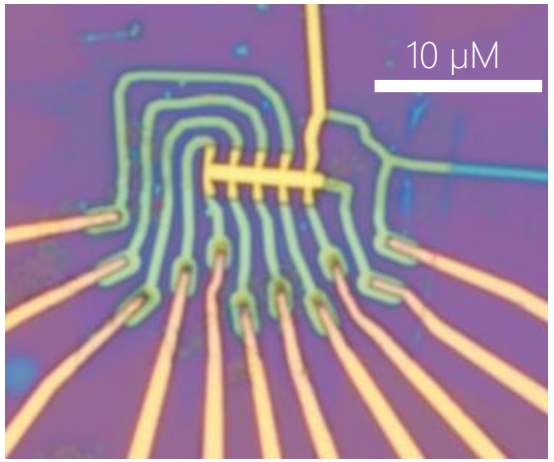


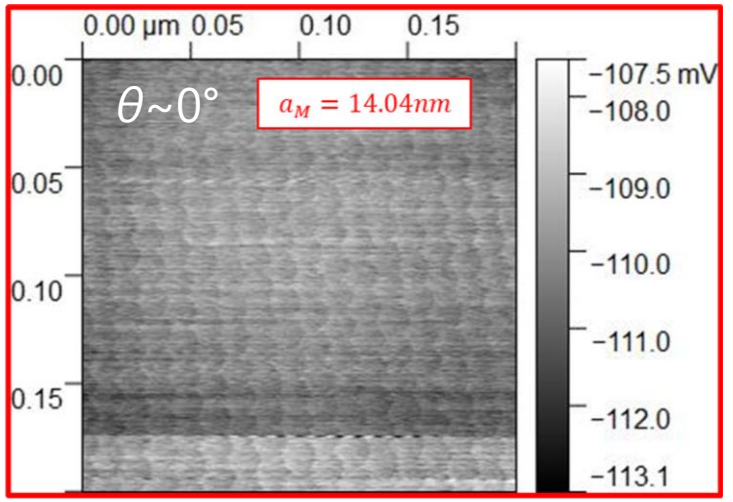


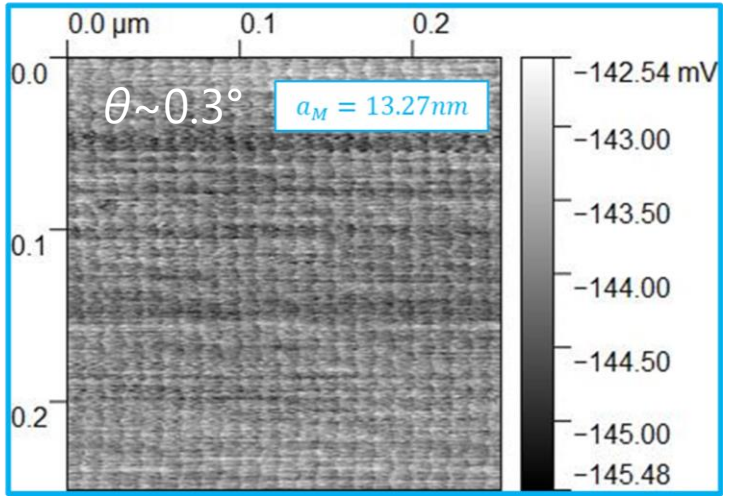
Kamat, Sharpe, et al. arXiv.2405.18588
Pendharkar, et al. PNAS (2024)

Deterministic fab with rapid feedback

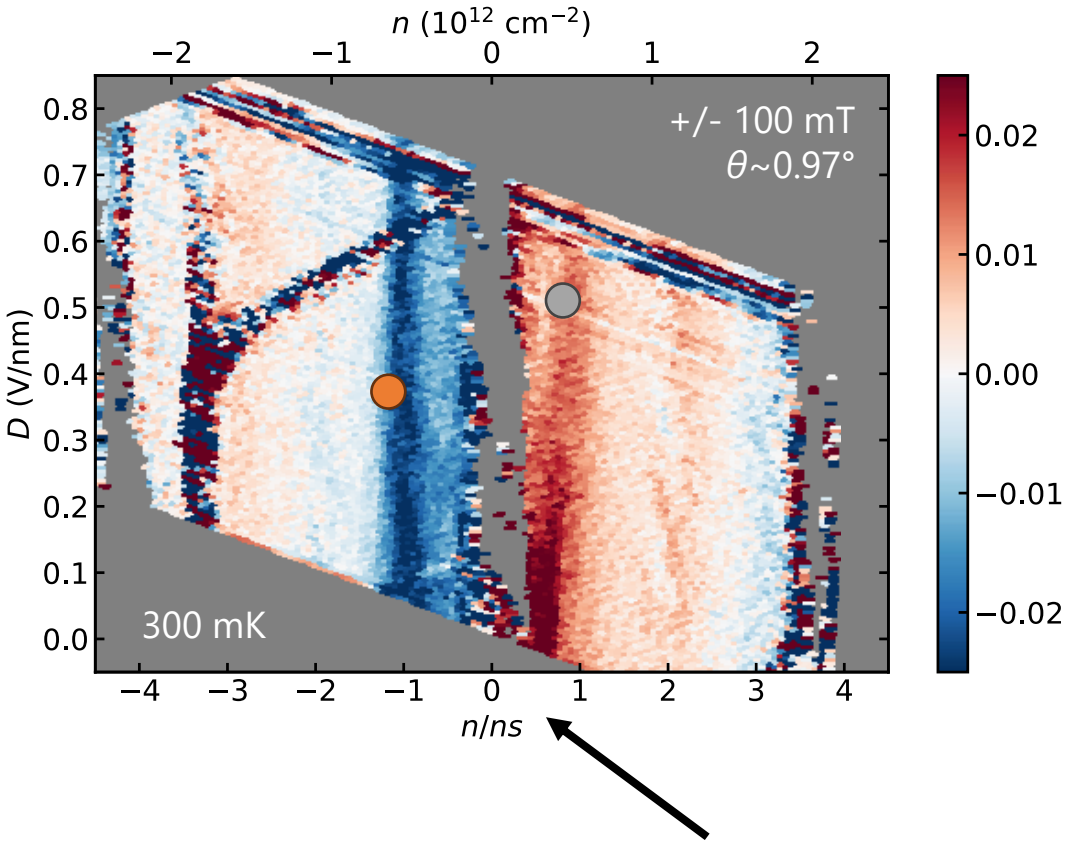




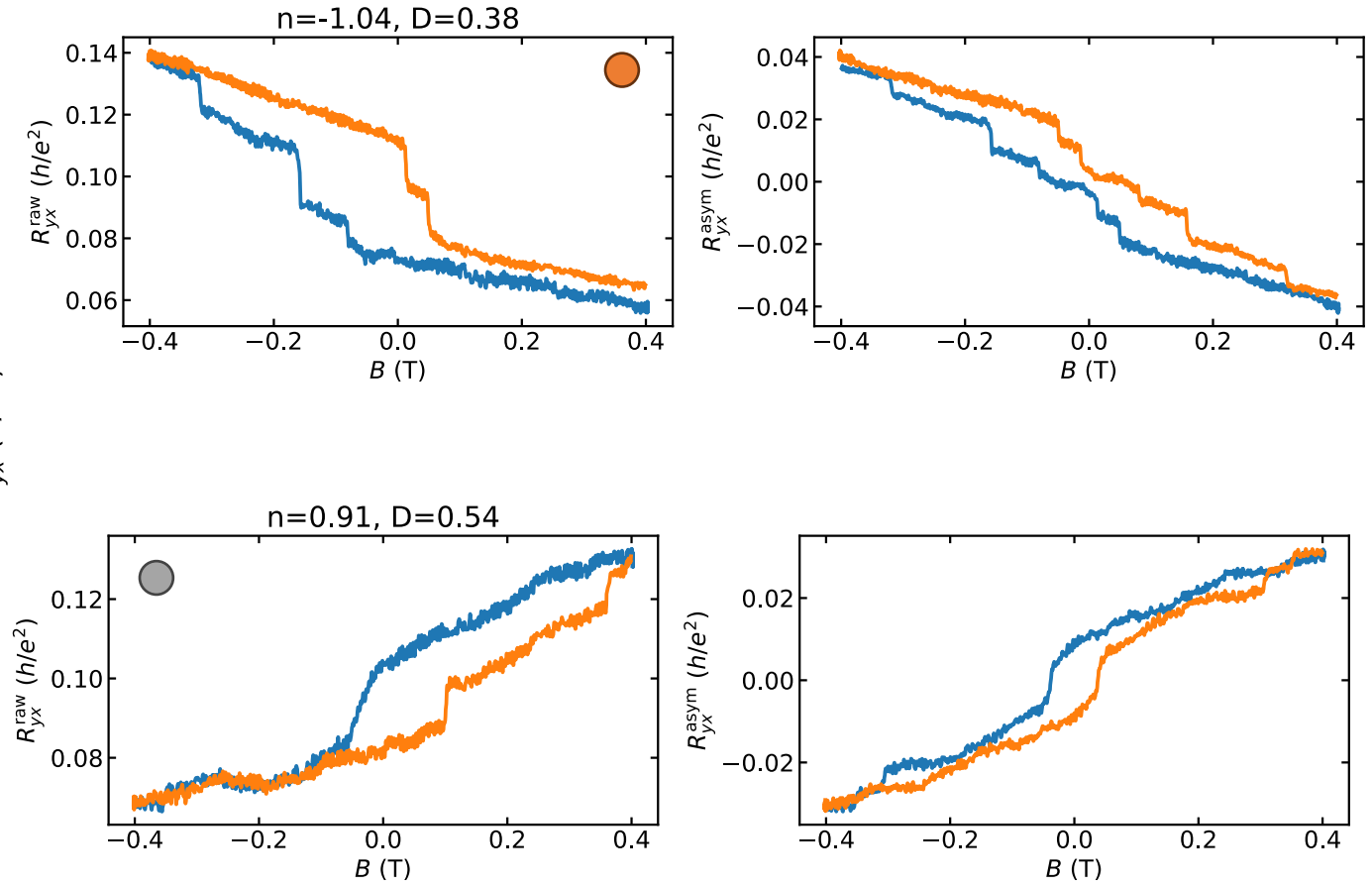




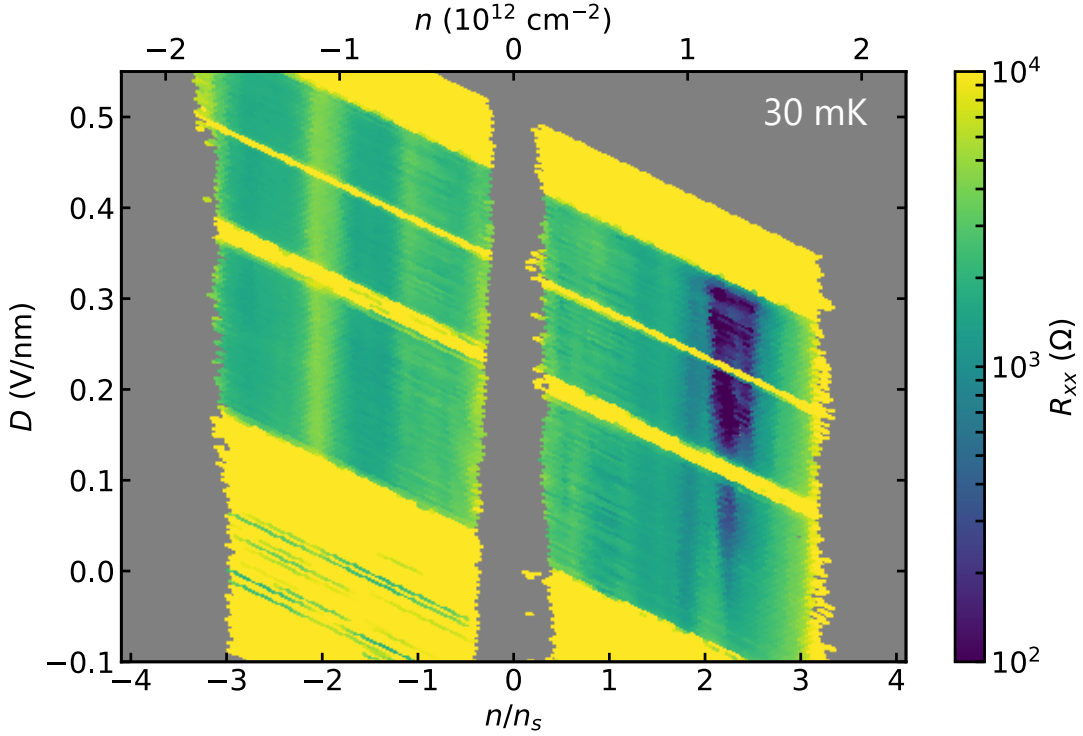
Anomalous Hall!

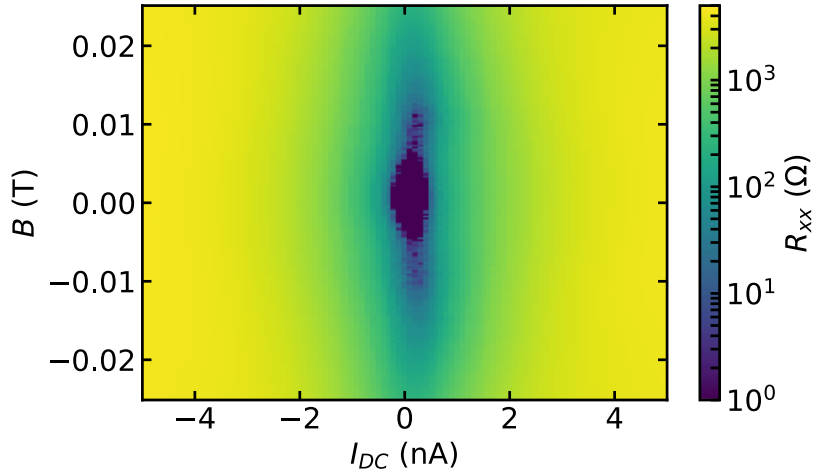


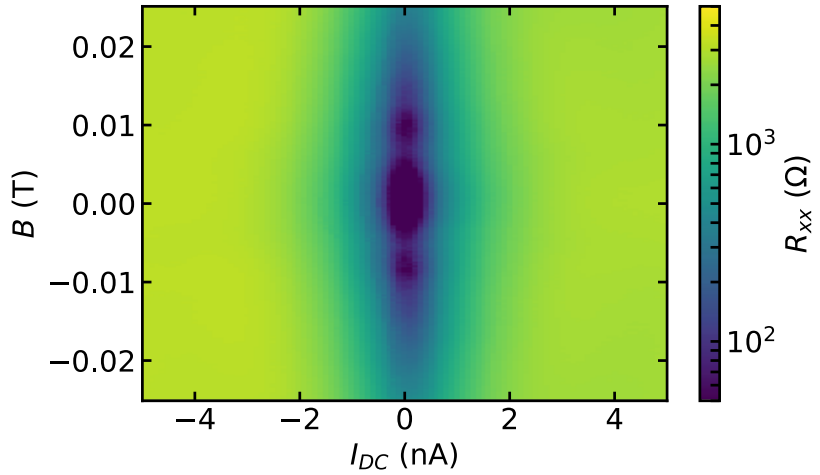
Large gap at CNP



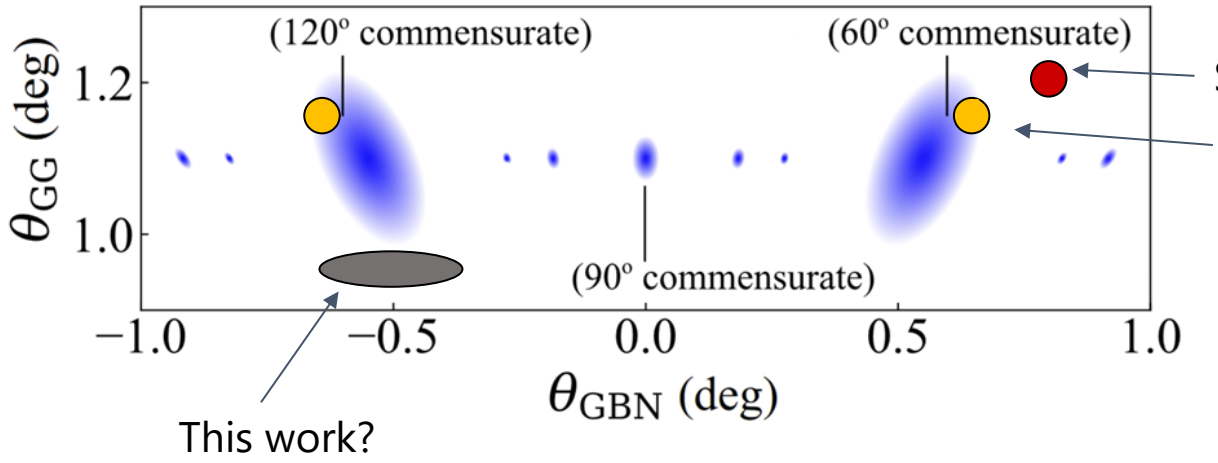
Cooling to 30 mK, superconductivity!?







What is θ_{GBN}? Let's speculate

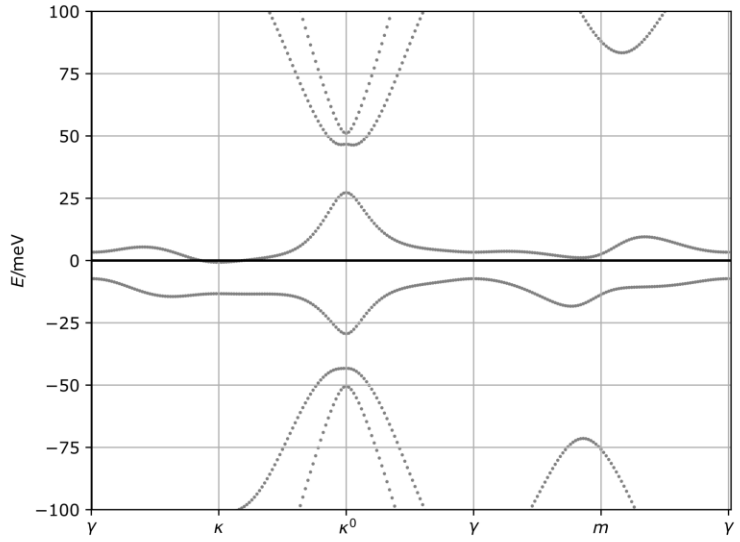


Sharpe, Fox, et al.

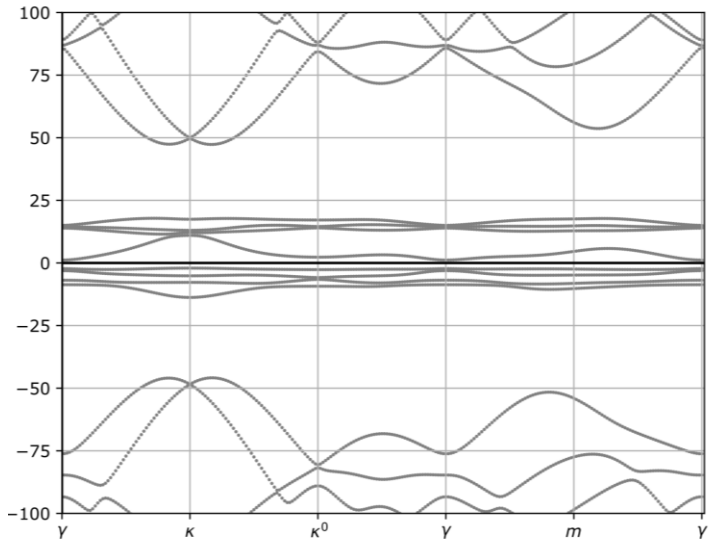
Serlin, et al.

This work?

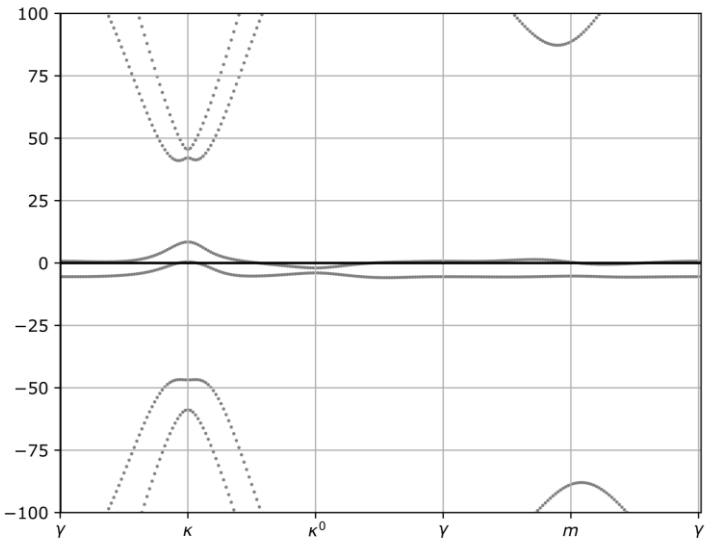
120 commensurate



90 commensurate



60 commensurate



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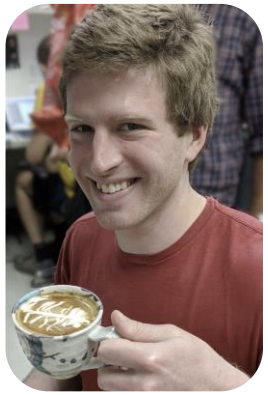
Sandesh Kalantre
Steven Tran
Greg Zaborski
Fang Liu
Jenny Hu
Tony Heinz
Marisa Hocking
Andy Mannix
Zoe Zhu
Julian May-Mann

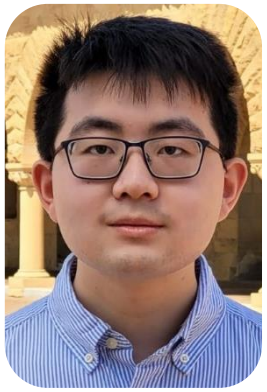
MIT:
Liqiao Xia
Aviram Uri
Sergio de la Barrera
Gregorio de la Fuente
Liang Fu

Princeton:
Yves Kwan

NIMS:
Takashi Taniguchi
Kenji Watanabe


Rupini Kamat

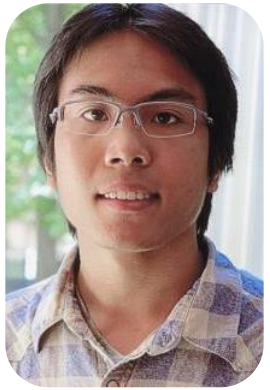

Eli Fox


Charles Yang

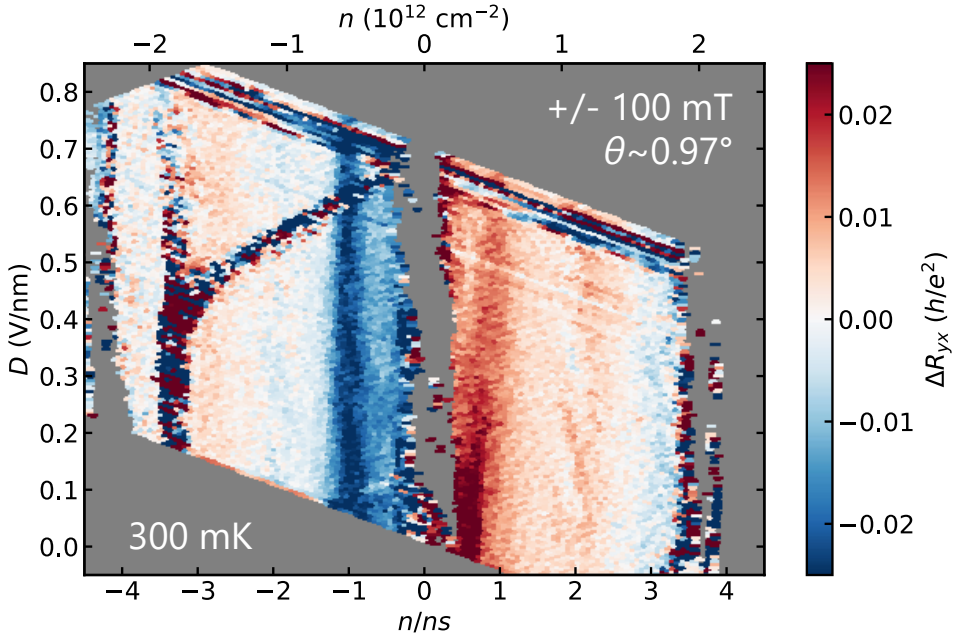

Skanda Rao

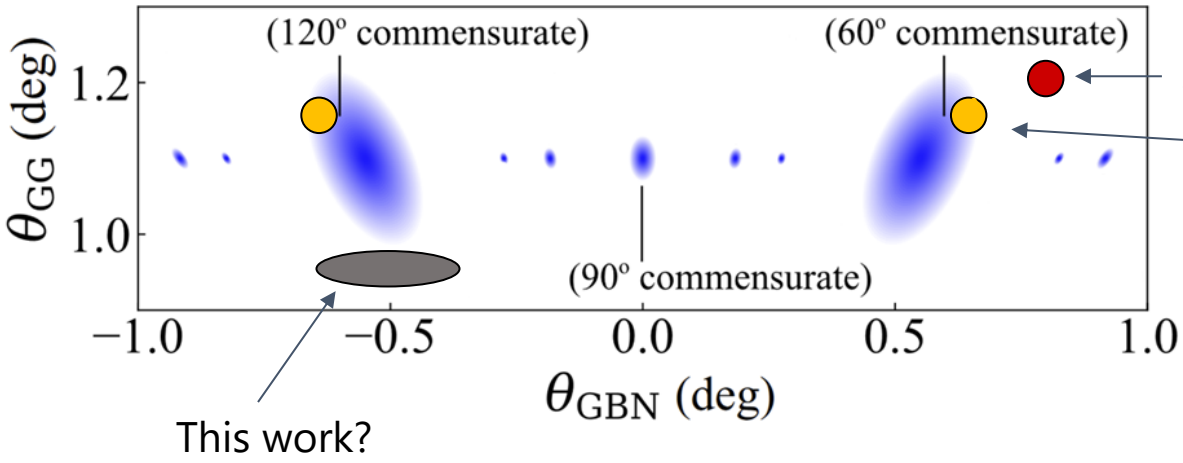

David Goldhaber-Gordon

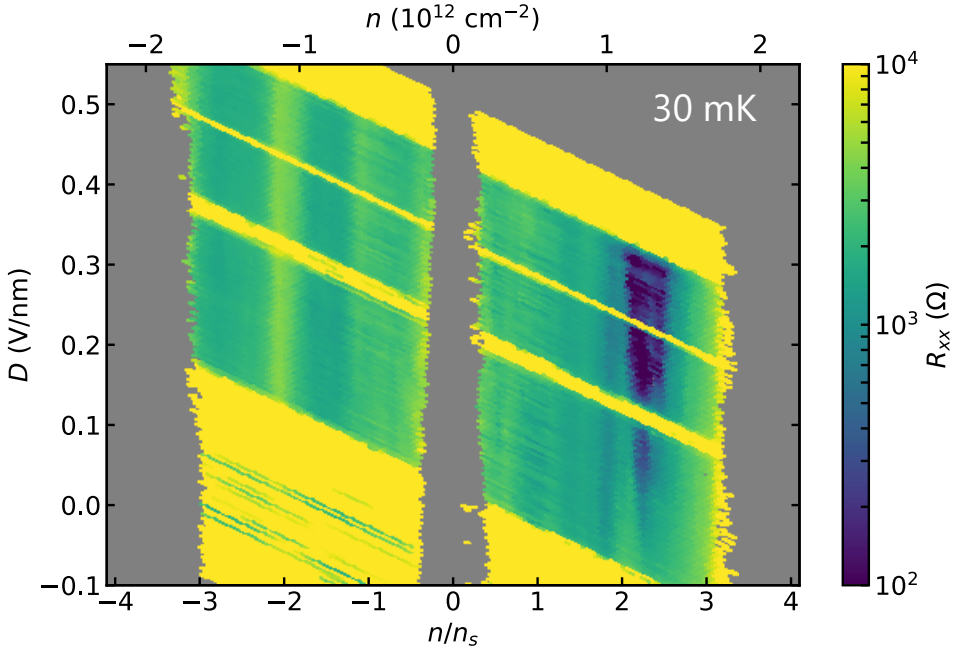

Marc Kastner


Trithep Devakul


Pablo Jarillo-Herrero







- Bottom up deterministic fab with intermediate characterization
- Fabricated TBG aligned to hBN:
  - Sample exhibits AH at +/- 1
  - Weak superconductivity in a C2 broken device?
- The hBN/TBG phase diagram may be quite rich!
- Happy to discuss additional HTG data